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Comparative Analysis of Bit Error Rate and Outage Capacity for MIMO Space Time Trellis Coding

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Abstract- In this paper, we have first given brief introduction to Multiple Inputs Multiple Outputs (MIMO) systems. After that different MIMO models and their capacity is discussed. We have compared bit error rate of different modulation techniques like Phase Shift Keying (PSK), Quadrature Amplitude Modulation i.e. QAM 16, QAM 32, QAM 64 using Space Time Trellis Coding (STTC). The outage capacity and bit error rate of MIMO and MISO have also been compared. The Rank criterion is used for maximizing the rank of transmitting antennas matrix in STTC. The proposed technique increases spatial diversity and coding gain of MIMO channels.

Keywords: *Spectral efficiency, Diversity, Spatial multiplexing, Bit error rate, Outage capacity*

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1. INTRODUCTION

In today's busy life, mobile phones have become inseparable part of our life. There are a large number of mobile phone users in any area. To increase spectral efficiency, instead of using single antenna, multiple antennas which work as smart antennas, are used. The multiple antenna systems also reduce fading effects. The term MIMO (Multiple Input Multiple Output) system refers to method of multiplying capacity of radio link by exploiting multipath propagation [1]. MIMO is most important element in wireless communication standards i.e. IEEE 802.11n or Wi-Fi, WiMax. When we use multiple transmitting and receiving antennas, the quality and capacity of the communication link improves [2]. The multi-input-multi-output (MIMO) technique provides spatial multiplexing and diversity gains [3].

2. MULTIPLE ANTENNA SYSTEMS

There are four communication models or multiple antenna systems i.e. SISO, SIMO, MISO, MIMO.

2.1 Single Input Single Output (SISO)

Single input single output systems have single antenna at transmitter and single antenna at receiver side.

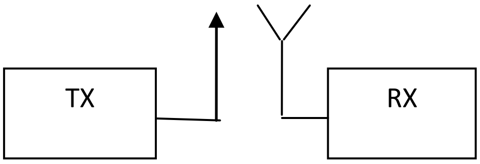

Figure 1: $N_T = N_R = 1$ Single-input, Single-output (SISO) system

No diversity techniques are used in this model. This model is being used since the advent of radio technology because it is simple and cheap.

2.2 Single Input Multiple Output (SIMO)

SIMO uses one antenna at transmitter side and multiple antennas at receiver side.

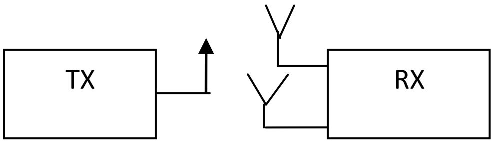

Figure 1.1(b): $N_T = 1$ and $N_R \geq 2$ Single-input, Multiple-output (SIMO) system

This model uses selection diversity or maximal ratio combining techniques. In Selection diversity, the receiver will choose antenna which is providing best signal. In maximal ratio combining (MRC), receiver combines signals from all antennas so that the signal to noise ratio get improved.

2.3 Multiple Input Multiple Output (MISO)

MISO system uses transmit diversity by employing multiple antennas at transmitter side and single antenna at receiver side.

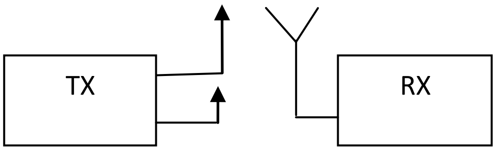

Figure 1.1(c): $N_T \geq 2$ and $N_R = 1$ Multiple-input, Single-output (MISO) system

Two antennas at the transmitter, one antenna at the receiver employs a transmit diversity technique. The Space Time Coding technique is used at transmitter side to transmit data in space & time domain [3].

2.4 Multiple Input Multiple Output (MIMO)

MIMO model employs multiple antennas at transmitter and multiple antennas at receiver side. The additional antennas provide increased system throughput. This model provides spatial multiplexing and diversity gains [4, 9]. Spatial multiplexing employs technique of transmission in which data is split into multiple streams and those streams are transmitted and received by multiple antennas [5].

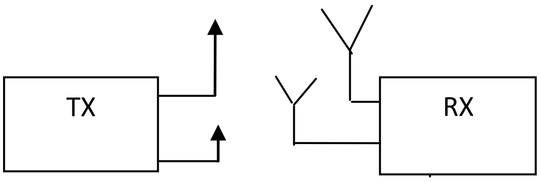

Figure 1.1(d): $N_T \geq 2$ and $N_R \geq 2$ Multiple-input, Multiple-output (MIMO) system

MIMO provides more channel capacity and data rate by using more transmit antenna. The multiple antennas are able to reduce fading and provide coding gains.

3. MIMO CHANNEL CAPACITY

If channel is characterized by $N_R \times N_T$ channel matrix H with elements $\{h_{ij}\}$. Using singular value decomposition, we can express channel matrix H with rank r as

$$\mathrm{H} = \mathrm{U}\,\Sigma\, V^H$$

where U is an N_R×r matrix, V is an N_T×r matrix, and Σ is $r \times r$ diagonal matrix with diagonal elements the singular values σ1, σ2,……., σ_r of the channel [8].

The orthogonality of column vectors U and V is maintained. The Singular value decomposition of the channel matrix H is

$$\mathrm{H} = \sum_{i=1}^{r} \sigma_i u_i v_i^H$$

where $\{u_i\}$ are the column vectors of U.

The $N_R \times N_R$ matrix HH^H can be decomposed as $HH^H = Q \wedge Q^H$ where Q is the $N_R \times N_R$ modal matrix and ∧ is $N_R \times N_R$ diagonal matrix. The singular values of H and eigen values of HH^H are mathematically related as

$$\lambda_i = \begin{cases} \sigma_i^2 & i = 1,2,\ldots\ldots\ldots\ldots.r \\ 0 & i = r+1,\ldots\ldots,N_R \end{cases}$$

Frobenius norm of H is defined as;

$$\|H\|F = \sqrt{\sum_{i=1}^{N_R}\sum_{j=1}^{N_T}\left|h_{ij}\right|^2}$$

$$= \sqrt{\mathrm{trace}(HH^H)}$$

$$= \sqrt{\sum_{i=1}^{N_R}\lambda_i}$$

3.1 Capacity of a Deterministic MIMO channel

For a frequency-nonselective AWGN MIMO channel characterized by H with N_T ×1 transmitted signal vector the received signal vector is defined by [8]

$$y = Hs + \eta$$

where η is the N_R×1 zero mean Gaussian noise vector with covariance matrix $R_{nn} = N_0 I_{N_R}$.

Channel capacity, $C = \max_{p(s)} I(s; y)$

$C = \max_{tr(R_{ss})} \log_2 \det(I_{N_R} + 1\frac{1}{N_0} H R_{ss} H^H)$ bps/Hz.

Applying decomposition $HH^H = Q \wedge Q^H$.

$$C = \sum_{i=1}^{r} \log_2\left(1 + \frac{\varepsilon_S}{N_T N_0}\lambda_i\right)$$

Capacity of SISO channel

For Single Input Single Output (SISO) channel

$C_{SISO} = \log_2(1+\frac{\varepsilon_S}{N_0}|h_{11}|^2/N_0)$ bps/Hz.

Capacity of SIMO channel

Single Input Multiple Output (SIMO) channel (N_T =1, $N_R \geq 2$) can be characterized by vector h= $[h_{11}, h_{21} \ldots h_{N_R 1}]^t$. The eigen value λ_1 is given as

$$\lambda_1 = \|h\|_F^2 = \sum_{i=1}^{N_R}|h_{i1}|^2.$$

Therefore capacity of the SIMO channel is

$$C_{SIMO} = \log_2\left(1+\frac{\varepsilon_S}{N_0}\sum_{i=1}^{N_R}|h_{i1}|^2\right) \text{ bps/Hz.}$$

Capacity of MISO channel

A Multiple Input Single Output (MISO) channel ($N_T \geq 2$, $N_R = 1$) is characterized by the vector h = $[h_{11}, h_{21} \ldots h_{1N_T}]^t$. The capacity of the MISO channel

$$C_{MISO} = log_2\left(1 + \frac{\varepsilon_S}{N_T N_0}\sum_{j=1}^{N_T}\left|h_{1j}\right|^2\right) \text{ bps/Hz.}$$

3.2 Capacity of Ergodic Random MIMO channel

The capacity of MIMO channel is expressed

$$C_{MIMO} = E\left\{\sum_{i=1}^{r} log_2\left(1 + \frac{\varepsilon_S}{N_T N_0}\lambda_i\right)\right\}$$

$$= \int_0^\infty \ldots \int_0^\infty \left[\sum_{i=1}^{r} log_2\left(1+\frac{\varepsilon_S}{N_T N_0}\lambda_i\right)\right] p(\lambda_1,\ldots\lambda_r)d\lambda_1\ldots d\lambda_r.$$

4. RANK AND DETERMINANT CRITERION

Given below is codeword difference matrix in which we used rank and determinant criterion.

$$B(x,e) = \begin{bmatrix} e_1^1 - x_1^1 & \cdots\cdots\cdots & e_1^{N_t} - x_1^{N_t} \\ \vdots & \ddots & \vdots \\ e_L^1 - x_L^1 & \cdots\cdots\cdots & e_L^{N_t} - x_L^{N_t} \end{bmatrix}$$

and a distance matrix expressed as

$$A(x, e) = B(x, e)\, B^H(x, e)$$

For a high value of signal to noise ratio, pair wise probability of error is described as

$$P(x, e) \le \left(\prod_{i=1}^{r} \lambda_i\right)^{-N_r} \left(\frac{E_s}{4N_0}\right)^{-rN_r}$$

where rank of matrix A(x, e) is r, and λ_1, λ_2, ..., λ_r denote its non-zero eigen values.

As we increase signal to noise ratio, the PEP decreases exponentially [8]. For Rayleigh fading channel, the design criterion of Space time coding demands that minimum rank of matrix should be maximized and minimum product should be maximized [10, 11].

5. CONCLUSION

By using 23 iterations, the bit error rate for different modulation techniques has been examined. In 23 iterations, the bar graph given below represents optimum bit error rate results for different modulation techniques i.e. PSK, QAM 16, QAM 32, QAM 64. The Chart 1 shows results which depicts that bit error rate decreases maximum for QAM 16 and then for QAM 64, QAM 32 and PSK for given symbol constellation.

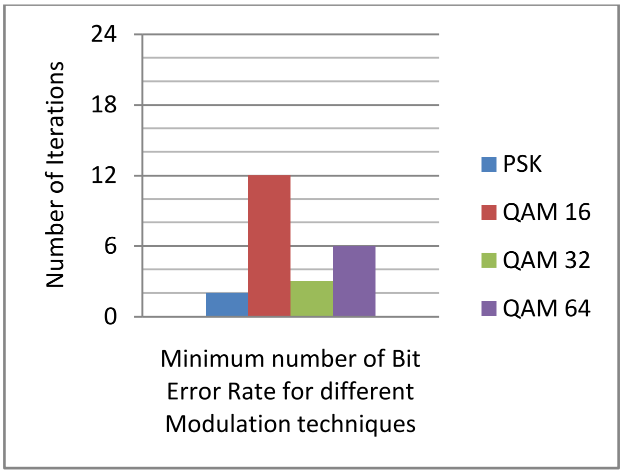

Chart-1: Minimum no. of Bit error rate for different modulation techniques

As shown in Figure-2, the based results for given signal to noise ratio, bit error rate remarkably decreases for QAM 16 as compared to PSK, QAM 64 and QAM 32. As the bit error rate decreases, the signal to noise ratio increases. The graph shows clearly that bit error rate decreases below 10^{-4} which is a better result of Space Time Trellis Coding using Rank criterion or Viterbi algorithm than Space Time Block Coding for different modulations.

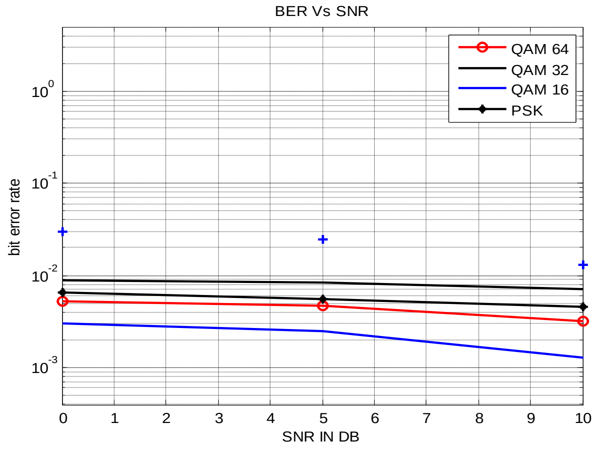

Figure-2: Bit Error Rate Vs SNR for different modulation techniques

The graph shown in Figure-3, gives comparison of bit error rate of MIMO with MISO under same channel equalization techniques like linear minimum mean square error (LMMSE).

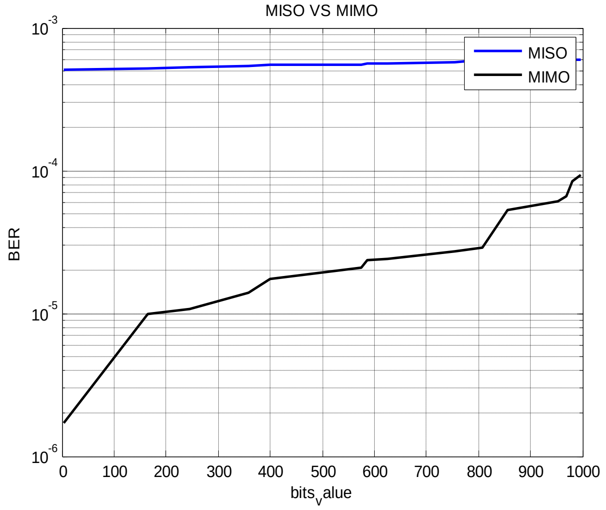

Figure -3: BER Vs Bit value for MISO and MIMO

The graph in Figure-4 depicts comparison of outage capacity of MIMO with MISO for given equalization technique and shows that MISO offers more outage capacity than MIMO. Consequently channel capacity of MIMO is more than that of MISO.

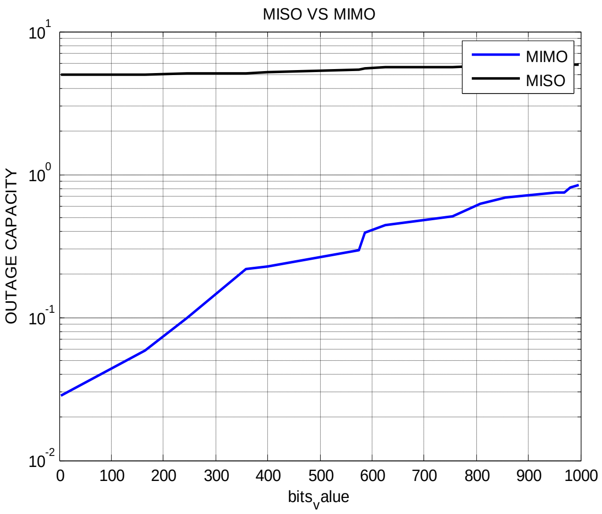

Figure -4: Outage Capacity Vs Bit value for MIMO and MISO

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BIOGRAPHIES

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